UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Electrification Administration

December 14, 1955

To: Distribution-type Borrowers and System Engineers

Subject: Distribution Transformer Loading

Attached is a copy of an Electric Engineering Division staff report on "The Distribution Transformer Loading Problem."

Many questions have come to our attention concerning the problem of loading distribution transformers practically and economically. It is a subject on which specific answers are not readily available. The electric utility industry has been seriously considering the matter in recent years; however, their answers, which apply primarily to multiple services, are not directly applicable to the situation on borrowers' rural electric systems where there is an average of 1.25 consumers per transformer.

As a result of conferring with borrowers and system engineers, our staff has developed some pertinent points of the problem, observations and indicated courses of action. These have been expressed informally in the attached discussion.

Since this subject is of such importance, we thought that you would be interested in having a copy of this discussion. It is not conclusive, definitive, or a recommended guide. Its purpose is to stimulate ideas and action. It may be that your experience and your thoughts, after reading the discussion, will prompt exploration of your own practices and accumulation of data. We also hope that you will submit your ideas, findings and data so that our engineers will be in a better position to consider the problem further.

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Attachment

THE DISTRIBUTION TRANSFORMER LOADING PROBLEM

(A Staff Report)

December 1955

RURAL ELECTRIFICATION ADMINISTRATION
UNITED STATES DEPARTMENT OF AGRICULTURE

THE DISTRIBUTION TRANSFORMER LOADING PROBLEM

INTRODUCTION

Load growth forces the system operators to face a very real transformer loading problem. With various forecasts indicating that the kilowatt-hour usage of rural consumers will double in anywhere from five to twelve years, many presently installed transformers will become overloaded within the foreseeable future.

Transformer and secondary installations are estimated to equal twenty percent of total plant investment. Installing excessive transformer capacity materially increases total plant investment.

Total transformer losses account for approximately three-fourths of the total system losses. When transformer capacity is increased, the excitation loss is increased to a greater amount than the resistance loss is decreased.

These facts justify continued concern regarding the selection of transformer sizes for new and replacement transformer installations as well as the limit to which existing transformer installations are loaded.

The Problem

If the system is "overtransformered", the result will be higher losses and higher investment. If the system is "undertransformered", the result will be excessive outages caused by transformer failures and excessive consumer complaints caused by low voltage and voltage flicker.

The transformer loading questions which must be answered are these:

1. What transformer capacity should be installed at new services or as replacements at old services:

    a. For single services?

    b. For multiple services?

2. What is the limit to which existing installations should be loaded, and which installations are approaching the limit:

    a. For single services?

    b. For multiple services?

Selecting Transformer Sizes

New Services

The selection of a transformer size for a new service must take into account

probable additions of major loads. Estimates of future load are admittedly rough approximations. Therefore, the procedure for selecting the transformer size cannot be precise.

There are approximately 1.25 consumers per transformer. Thus, the majority of selections will be for single services. Table I will serve as a guide in selecting the transformer size for single services. The consumers are classified by the major electrical loads expected to be in use by the consumer within the near future.

To illustrate the use of the table, let us assume that a new service is to be connected. An interview with the new property owner reveals that the presently owned appliances are an electric water heater and an out-moded gas range, but no other major loads, and that the owner indicates he prefers an electric range and plans to purchase an electric clothes dryer. In accordance with the table, the correct selection would be a $7\frac{1}{2}$ kva transformer, whereas the present load would indicate that a three-kva transformer is sufficient. Such an interview will reveal to the operator the probability and timing of future major loads being added to the consumer's load and will very definitely influence the selection of transformer size to be installed.

Rural distribution systems will include some transformer installations serving more than one consumer. Table II will serve as a guide in selecting the size transformer to be used when more than one consumer is served from the transformer. The following example will illustrate the use of the table.

The system records indicate that five consumers will be connected to the transformer. An interview with the five consumers reveals that they will have the following: two water heaters, three ranges, one electric clothes dryer, and two one horsepower air conditioning units. Reading from the table, the load requirements for the transformer would be 2.3 kw for all minor loads, 2.1 kw for the two water heaters, 7.2 kw for the three ranges, 2.0 kw for the one dryer, and 2.0 kw for the two air conditioners. The sum is 15.6 kw for which a 15 kva transformer would be installed. The 15 kva transformer would provide for the initial planned load plus a reasonable additional capacity to provide for load growth.

As in the selection of transformer sizes for single services, the selection for multiple services must be based upon the knowledge resulting from an interview and inspection of the consumers to be connected from the transformer.

Replacement of Existing Transformers

When a transformer is to be replaced and no knowledge exists concerning the past load of the service, the replacement transformer size will have to be selected in a manner similar to that outlined for new services. Frequently measurements are available which provide the existing load levels of the transformer installations. When the present load level is known, the selection of the transformer size should be based upon that load level plus a reasonable increase to provide for load growth.

Loading Limits

Single Services

The maximum recommended load for a distribution transformer serving one consumer is 140% of the nameplate rating. The specific limits for common sizes of transformers are given in Table III. The 140% value is based upon voltage flicker considerations and minimum primary voltage coincident with maximum consumer load. The maximum kva values given in Table III are for one-half hour integrated demands.

Multiple Services

The maximum recommended load for a distribution transformer serving more than one consumer is based upon minimum primary voltage and thermal limits. Voltage flicker is not usually a consideration when establishing load limits for a transformer on multiple services. Specific values are given in Table IV. The maximum load in percentage of nameplate kva values is based on one-half hour integrated demand.

Loading Existing Transformer Installations

Correlation of Kilowatt-hours Per Month to Demand

The electric distribution industry has for many years found it possible to establish a relationship between the total kwh/mo. and the resulting demand on a transformer. These correlations were developed from measurements and were for multiple services only. The correlation proved to be of great value in predicting transformer load.

It has been frequently suggested that a similar technique be employed to estimate transformer loads on rural distribution systems. A rural distribution system is fundamentally different in that a great majority of the transformers serve one consumer. Whereas the diversified demand resulting from the individual demands of several consumers can be accurately correlated to the total consumption, the same does not appear to hold true when only one consumer is served from a transformer. The attached graph is a plot of kw demand versus kwh/mo. for 233 individual farm consumers. This graph illustrates the wide variation in demand resulting from a specific consumption level. For example, for two consumers which use 330 kwh in one month, the demand for one is 1.4 kw and for the other 5.9 kw. Whereas the data indicates an average demand of 4.2 kw for consumers using 390 kwh/mo., the average value would be of little use in estimating the demand for an individual transformer. This is true because of the large deviations from the average.

In obtaining the data for the attached graph, no attempt was made to divide the consumers into major groups classified in accordance with the major load units in use. It is assumed that a similar plot for a group of consumers using a range would result in a better correlation. This assumption is based on the fact that a range load tends to decrease individual load factors. Other major load units, such as a water heater, tend to increase individual load factors. A possible grouping which may result in a better correlation of kwh/mo. to kw demand would be the following:

1. No Major Load Units
2. Water Heater Only
3. Range Only
4. Water Heater and Range
5. Water Heater and Dryer
6. Water Heater, Dryer and Range

Test data may reveal that the classifications or groupings could be reduced in number.

The test data plotted on the attached graph is for rural consumers located in various regions of the country. Test data recorded for groups of consumers in a localized area might result in a somewhat better correlation of kwh/mo. and kw.

A test program is required in order to obtain the necessary data from which a correlation might be established. Since transformer load is more closely a function of ampere demand than of kilowatts, it is recommended that ampere demand be measured. A three-wire, socket-mount, thermal-type ampere demand meter used in conjunction with a two socket test trough would provide a very simple and convenient test installation. The attached photograph illustrates a typical test installation. It is estimated that 60 readings would be required for each group of consumers. If 6 groups are used, a total of approximately 360 measurements would be required. The meter installation would be installed for one month, the value of kilowatt-hours and ampere demand recorded, and the meter moved to a new location.

As stated previously, a usable correlation can be determined between the total kwh/mo. served by a multiple service to the maximum demand. Such correlations have been established and effectively used by the industry for some time. The correlation is established by conducting tests where ampere demand is measured at the transformer and the total kwh/mo. obtained from billing records. Data appearing in the literature indicates that relatively few tests would be required to establish a reasonably accurate correlation. The testing program would be similar to that described for single services except that instrumentation would be different. Any meter from which maximum integrated half-hour ampere demands can be determined would be suitable. The meter is installed at the transformer and measures all loads supplied by the transformer. Correlations published in the literature are for multiple services of ten or more consumers. A majority of multiple services on rural systems would serve approximately 2 to 5 consumers. It is therefore necessary that the correlation be established by the individual system for its use.

Estimating Transformer Requirements

The data plotted in the attached graph indicates that on the average, consumers using less than 160 kwh/mo. require a $1\frac{1}{2}$ kva transformer, consumers using between 160 and 390 kwh/mo. require a 3 kva transformer, consumers using 390 to 1000 kwh/mo. require a 5 kva transformer, and consumers using more than 1000 kwh/mo. require a $7\frac{1}{2}$ or larger kva transformer.

By making use of these average limits it is possible to estimate the quantity of each size of transformer required by the system for the present usage level. The first step is to complete a consumption analysis for all single services. Table V is a tabulation of a consumption analysis for a system having an average usage of 206 kwh/mo. for single services.

A relatively new system having just completed a large amount of construction involving the addition of numerous consumers would find that such a consumption analysis would indicate the system to be "overtransformered". This is expected in that many transformers have been recently installed anticipating some load growth. Older systems should find a closer correlation between the quantity and size of transformers actually installed and the quantity and size indicated by the analysis.

This method of analysis serves as a check or guide for the transformer loading condition on the system. Where excessive transformer capacity has been installed, this analysis would reveal the situation and should indicate a modification of past practices.

A second means of keeping a check on the relative transformer capacity installed is to compare the total connected kva of distribution transformers to the substation peak kw demand. As the weighted age of the consumers in the substation area increases, the ratio of total transformer kva divided by substation kw demand should gradually decrease. A sudden increase in the ratio should be accounted for by a large number of consumers being added. An ideal ratio cannot be established for any given system. The value of establishing a ratio and maintaining a continuous record is that it serves as a guide. If the ratio does not gradually decrease, it is an indication that past practices of transformer loading should be reviewed.

Consumer Connected Load Records

Complete records of consumer connected load can be very effective in preventing over-loaded distribution transformers. If it is known when a consumer has added a major load such as a clothes dryer or range, a check on the size of transformer now installed and on the other loads now in use will very often indicate that a change in transformer size is required. A set of complete records listing transformer size, consumer's name, maximum KWH/mo. used, and a list of the major loads now in use are necessary.

Numerous methods and techniques have been used to maintain a complete set of records. For example, data is collected at the annual meeting, when consumers come to the office to pay power bills, by mail inquiries, from appliance dealers, in conjunction with power use studies, etc. Usually some incentive is used to encourage members to supply the required data. Any of these methods which prove efficient for maintaining the records may be used.

Demand Meters

An ideal solution for determining transformer load is to have ampere demand or kw demand meters for each transformer and service installation. The consumer would be instructed to read the meter, reset the meter, and send in the reading along with his self-billing card. In this way, an exact value of demand would be obtained and there would be no question concerning the transformer load. The obvious difficulty is that the meters would considerably increase system investment and their use is not recommended.

Internal Secondary Breakers

Internal secondary breakers are designed to protect the transformer against damage from overload but they do not necessarily prevent overloads that may cause unsatisfactory voltage conditions. For this reason, tripping of secondary breakers should not be used as an indication of overload. This practice generally leads to special service calls and excessive interruptions.

Overload Indicators

Several types of overload indicators are available for distribution transformers. These devices are calibrated to indicate when a transformer is approaching thermal overload. The red light signal available on transformers which incorporate an internal secondary breaker is one type of overload indicator. It has been suggested that these devices be employed to indicate which transformers are overloaded. Although they have been successfully employed on urban systems, it is questionable that such would be the case on a rural system. If they were employed on a rural system, it would probably be necessary to patrol the system in order to identify the overloaded transformers. The cost of patrolling the system would no doubt be excessive. Also, since a large number of the present transformer installations do not include an overload indicator, such a device would be of little help in solving the immediate problem.

The same limitations for using overload indicators on transformers serving one consumer apply to their use on transformers serving more than one consumer. Transformer installations on a rural system are widespread throughout the system and some means other than patrolling the system would have to be devised as a means of locating the overloaded transformers.

SUMMARY

1. The first step in seeking a solution to the transformer loading problem will very definitely be that of establishing complete and up-to-date transformer records and consumer records. These records must include the size of transformer serving the consumer, major load units used by the consumer, and the maximum KWH/mo. comsumption.

2. Since a very large number of transformer installations will require replacement within a ten year period due to load growth, considerable time and effort are economically justified in connection with this problem.

3. The major drawback to allowing distribution transformers to become overloaded is that replacement costs will become excessive and consumer relations will be impaired.

4. The major drawback to installing excessive transformer capacity is that system losses and investment will be higher than justified.

5. Although it is doubtful that an accurate correlation of KWH/mo. to demand has been established for single services, it is hoped that a usable correlation can be developed if the consumers are grouped in accordance with major appliances in use.

6. A test program to establish a correlation between total KWH/mo. and demand for multiple services should produce sufficiently accurate data to solve transformer loading problems of multiple services.

7. Conventional overload protection devices which interrupt services do not appear to be a solution. The protection device disconnects load at a higher than maximum operating level and discontinues service. This results in expensive service calls and poor consumer relations.

8. If thermal overload indicators are to be successfully used on future transformer installations, some economical and reliable method of notifying the operator which indicators have operated must be developed.

9. An accurate record of the major loads used by each consumer will be of great value.

TABLE I

TRANSFORMER SIZES FOR SINGLE SERVICES

Major Load Units*	Transformer Size	Major Load Units*	Transformer Size
None	1½	Range & Room Air Conditioner 3/4 hp	5
Water Heater	3	Water Heater, Range, & Clothes Dryer	7½
Range	5	Water Heater, Range & Room Air Conditioner 3/4 hp	7½
Clothes Dryer	5	Water Heater, Clothes Dryer & Room Air Conditioner 3/4 hp	5
Room Air Conditioner 3/4 hp	3	Water Heater, Range, Clothes Dryer & Room Air Conditioner	10
Water Heater & Range	5		
Water Heater & Clothes Dryer	5		
Water Heater & Room Air Conditioner 3/4 hp	3		

* Major load units not included in the table must be considered separately and the transformer size increased as required.

TABLE II

TRANSFORMER SIZES FOR MULTIPLE SERVICES

Number of Consumers	KW Demands*				
	All Minor Loads	Water Heater	Range	Clothes Dryer	Air Conditioner***
1**	.8	1.2	3.6	2.0	1.0
2	1.2	2.1	5.8	3.3	2.0
3	1.6	2.9	7.2	4.2	3.0
4	2.0	3.6	8.4	5.0	4.0
5	2.3	4.3	9.4	5.8	5.0
6	2.6	4.9	10.4	6.5	6.0
7	2.9	5.5	11.2	7.2	7.0
8	3.2	6.2	12.0	7.8	8.0
9	3.5	6.8	12.8	8.4	9.0
10	3.8	7.4	13.6	9.0	10.0

* Major load units not included in the table must be considered separately and the transformer size increased as required.

** See Table I.

*** KW per horsepower installed.

TABLE III

MAXIMUM LOAD FOR DISTRIBUTION TRANSFORMERS SERVING

ONE CONSUMER

Transformer Name Plate Rating	Maximum Load Amperes 120-volts	Amperes 240-volts	KW 90% PF	KVA
$1\frac{1}{2}$	17.5	8.75	1.9	2.1
3	35.0	17.5	3.8	4.2
5	53.3	29.1	6.3	7.0
$7\frac{1}{2}$	87.5	43.8	9.4	10.5

TABLE IV

MAXIMUM LOAD FOR DISTRIBUTION TRANSFORMERS

SERVING MORE THAN ONE CONSUMER

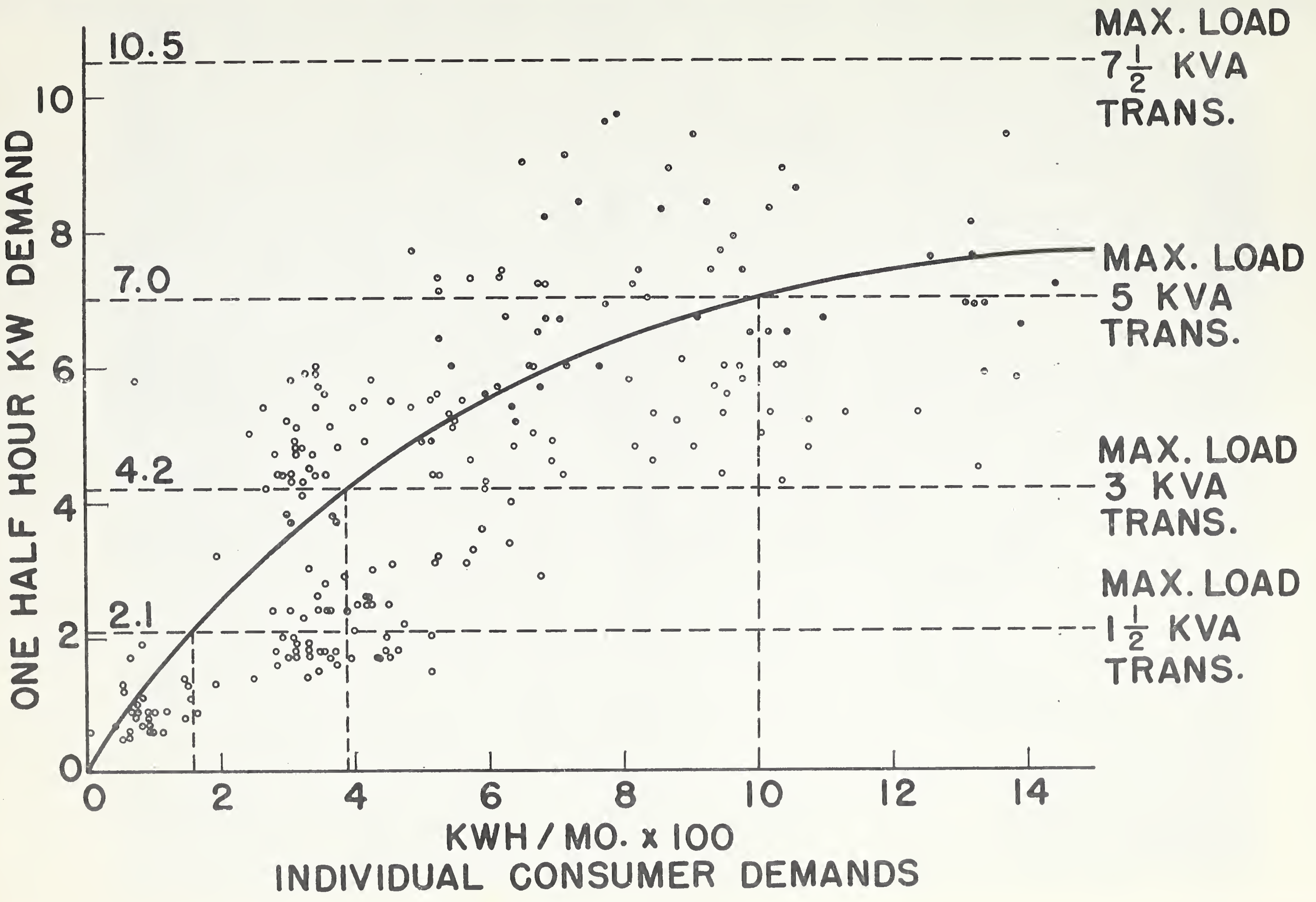
Number of Consumers	Maximum Load In Percent of Nameplate Reading	Minimum Permissible Primary Voltage* (on 120-volt base)
1	140	116
2	150	117
3	160	118
4	170	119
5	180	120
Above 5	180	120

* If the primary voltage is less than stated in the table, maximum load must be decreased proportionately.

TABLE V

Consumption Analysis Summary

KWH/mo. Used	Number of Consumers	Transformer Size Required
0-160	2758	$1\frac{1}{2}$
161-390	1561	3
391-1000	290	5
above 1000	17	$7\frac{1}{2}$ or larger
	4626	



ONE HALF HOUR KW DEMAND
0
2
4
6
8
10
10.5
7.0
4.2
2.1
MAX. LOAD 7 1/2 KVA TRANS.
MAX. LOAD 5 KVA TRANS.
MAX. LOAD 3 KVA TRANS.
MAX. LOAD 1 1/2 KVA TRANS.
0
2
4
6
8
10
12
14
KWH / MO. x 100
INDIVIDUAL CONSUMER DEMANDS